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# FACTORS AFFECTING THE SUPPLY OF STRATEGIC RAW MATERIALS WITH PARTICULAR REFERENCE TO THE AEROSPACE MANUFACTURING INDUSTRY

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SUMMARY

The study analyses the political and strategic factors affecting the supply of certain raw materials critical to the European NATO aerospace industry. For various reasons, including potential political instability, concentration of sources, small scale of production and technological-industrial problems, chromium, cobalt, hafnium, manganese, niobium, titanium, tungsten and vanadium are all considered to a degree at risk.

## 1. INTRODUCTION

Much simplistic polemic has appeared on the subject of strategic raw materials, but it is in reality a complex topic involving aspects of many substantive fields, including particularly, geology, technology, economics and politics with geopolitics (Fig 1).

### Definitions

With regard to raw materials, the term 'critical' has normally been taken to imply a high degree of need within the defence industry. However owing to the wide ranging nature of that industry, allied to the fact that national power involves the total economic base, criticality has been applied more broadly.(1) In the present context the term is related to one specific industry (Fig 2).

The term 'strategic' has been used to denote a high level of import dependence and therefore geopolitical vulnerability.(2)

Recent literature has tended to combine all aspects of vulnerability and dependence in the one term 'strategic'. In the present study, for a raw material to be thus designated the following conditions must obtain:

(a) there must be a marked degree of import dependence;

(b) there must be a very limited number of significant suppliers;

(c) the material must be critical for the aerospace and directly associated industries.

All the criteria can be qualified. For example rather than a total geological absence of a raw material, import dependence may only imply that the costs of domestic recovery are at present uneconomic. Again, import dependence may result from a lack of technology, energy sources or sufficient market incentive. For these reasons many countries import partly processed ores and ferro materials.

Vulnerability clearly results when there is concentration on only a few sources which between them supply a high proportion of the raw material (Fig 3). In general terms the fewer the sources the greater the vulnerability although obviously the reliability of each must be taken into consideration. When there are only limited world producers of a particular mineral, there is no escape from concentration but in other cases, reliance on a few sources may occur for other reasons such as historical connections or the quality of the product. At a stage further removed, the known pattern of world reserves may dictate that at least in the short to medium term there is no alternative to concentration. Furthermore there may be indirect dependence when imports are taken from one country which itself obtains supplies from another. For example cobalt may be obtained directly from Belgium - Luxembourg but the true reliance is upon Zaire, the original source. Moreover the picture can be altered radically by substitution and recycling.

A further element to be considered is the scale of world production since if a raw material is scarce and also only available in small quantities it is far more vulnerable. (2) Not only can supplies be comparatively easily interdicted but investors can affect the market. On the other hand, transport can perhaps be by air and stockpiling is a more reasonable proposition. Conversely if an industry uses very

large amounts of raw material, speculation is unlikely to affect supplies but stockpiling presents far greater problems.

In some ways advancing technology reinforces dependence. For example, once a particular metal has been accepted within an alloy, the time required for substitution together with all the testing militates against changes. Furthermore any substitute is unlikely to be completely congruent in all the characteristics required. A further point of significance is that most of the strategic raw materials have a range of uses, many of which are not connected directly with sensitive industry. Therefore the approximate percentage of use which can be validly labelled strategic, needs to be ascertained. If of course this is only a minor percentage, then other supplies can, if the expertise is available, be converted in time of stress. If on the other hand most of the raw material is used in strategic industry this renders the situation even more acute. There is also the question of relative cost in that the cost of the strategic may be very limited compared with the overall cost of the equipment. Therefore a large price rise would have little effect on usage. On the other hand of course, the materials used in bulk are very much more sensitive to price rises.

Political pressures

If a raw material comes from basically one foreign source, no matter how close that source geographically or ideologically, there must always be some vulnerability. Political change may occur, local events such as strikes may affect supplies and perhaps, more obviously, the country may require the material for itself and limit exports. Thus even supplies from within European NATO itself cannot be considered totally safe.

The same problems apply to sources in the USA and Canada with the additional problem of the 'Atlantic Bridge'. The difficulty of shipping raw materials across the Atlantic will depend of course upon the length of time during the build-up to any conflict. With a period of increasing tension, it is possible that sufficient strategic raw materials could reach Europe, but on the other hand, the sudden war scenario precludes such movements.

Several neutral countries such as Finland, Sweden and Austria provide strategic materials and during a period of tension, it is more difficult to foresee their reaction. Finland in particular enjoys close relations with the USSR and is clearly susceptible to Russian pressure.

European NATO is also dependent upon materials from Australia, South-east Asia, Japan and China. These very extended sealanes of communication, impossible to protect other than at particularly sensitive points, indicate a further source of vulnerability. With a transit period of more than four weeks, the time factor becomes especially important.

Furthermore European NATO depends to a certain extent upon supplies from Centrally Planned Economies (CPEs), particularly the USSR and China. These of course represent a different order of vulnerability in that, in the event of increasing tension, it can be assumed that supplies would be denied. However at present it seems highly improbable that the two main suppliers would act together. Other CPEs involved in such trade include Yugoslavia, Albania and a number of African states, notably Gabon. In the case of the latter group, the fear must be that Soviet pressure could lead to a change of trading practice. However such developing countries are particularly dependent upon revenues from their raw materials and the USSR is generally unable to supply economic aid other than that involving arms.

Nonetheless the importance of a particular raw material within the export trade of a country must be considered. For example if it accounts for only some 1% or 2% of the total value, supplies to consumers might be reduced or halted with only very modest effects internally.

Finally, southern Africa (3) needs to be treated separately. Not only is it a highly volatile area with the USSR and its surrogates involved, but it is a long way from Europe and South Africa itself of course poses a number of moral problems (Fig 4).

Thus in the case of all the major suppliers: USA, Canada, Australia and South Africa, there are potential difficulties. For example even in the case of the USA, titanium supplies were stopped at one stage and the total output was diverted for domestic consumption. The nickel supplies from Sudbury were affected by an eighteen month long strike while in Australia industrial relations problems are also a potential hazard. In contrast to these, South Africa is a consistent and regular supplier but, some would say, at what cost? The long term outlook for South Africa must cause some alarm. (4) These are of course all peace time scenarios and in the event of war the maintenance of supplies could only be guaranteed through stockpiles.

A further potential difficulty has resulted from the development in the supplier countries of refining, beneficiation and further stages of manufacturing. Thus the materials appear in trade in semi-processed form and processing facilities become

redundant in the consumer countries. They therefore become dependent upon the producers not only for the ore but also for the further stages involved. This in turn of course affects the form in which materials can be stockpiled and poses problems of stockpile conservation and maintenance.

In conditions short of an incipient superpower conflict, supply problems can be looked at over a number of time spans. In the very short to short term, price changes are likely to exercise the major influence. These could be generated by anything from a natural catastrophe to trade union activity or stock market neurosis although for various reasons the development of cartels is judged unlikely. In the short to medium term local conflicts or extreme industrial action are likely to exercise the greatest influence. The problems of maintaining cobalt supplies from Shaba province, Zaire, in 1978 and the prolonged strike at Sudbury in 1969 are examples. The most obvious long term blockage would probably result from the actions of the USSR in South Africa. In peace time the most likely problems would seem to be those caused on a local level over a short to medium time span. These might involve: normal market fluctuations, industrial action, civil unrest, local conflict or sabotage.

However, it must be stated that in attempting to construct any model which might be applied to identify which raw materials can be considered strategic, the geopolitical input is as yet more speculative and less sophisticated than for example the geological (Fig 1).

## The aerospace industry

According to a recent survey (5) the following European NATO countries are concerned with production in different areas of the industry:

(a) Multinational aircraft: Italy, France, the UK and West Germany;

(b) Military aircraft: France, the UK, Italy, the Netherlands and West Germany;

(c) RPVs and Drones: Belgium, the UK, France, Italy and West Germany;

(d) Surface effect vehicles: France and the UK;

(e) Spacecraft: France, European Space Agency (ESA) and NATO;

(f) Research rockets: France and the UK;

(g) Missiles: France, the UK, Norway and West Germany;

(h) Gas turbine engines: France, the UK, Italy and West Germany;

(i) Rotary wing aircraft: France, the UK, Italy and West Germany.

Thus European NATO is well represented in all branches of development and research in the aerospace industry although four countries are particularly dominant.

In investigating the raw materials considered strategic for the aerospace industry (Fig 2), the vast range of products must be borne in mind. Apart from this the machine tools and a wide variety of other equipment required to construct them must be considered. Thus if the line of production is followed back, many other materials not directly involved in the actual manufacture of aircraft could be designated strategic. A further example of the variety of components involved can be given if the control systems are considered. The operation of the engine and other vital units is often controlled by computer and electronic systems. Thus the whole field of semi-conductors becomes vital to the aerospace industry and this of course has its own strategic requirements.

## Raw materials

Problems with the collection and anlysis of world-wide data on the production and reserves of raw materials together with the pattern of trade, have been well rehearsed elsewhere. However the points particularly relevant to the materials under consideration in the present study need to be stressed. Several strategics are produced through comparatively small companies in Third World countries and there must always exist some doubt as to the reliability of production data. Furthermore in any country where only one or two firms are involved there is often a problem of confidentiality. This may result in no figures being listed or a broad estimate being included. Then the materials themselves may come in a variety of grades and beneficiated states, and equating these causes problems. Furthermore increasingly, recycled sources are coming into play, frequently in countries not concerned with ore production, and assessment of the magnitude of production particularly of new scrap, may again be conjectural. This obtains particularly when both old and new scrap are concerned. As was shown earlier, the scale of production has a very great bearing upon problems of vulnerability and dependence.

With regard to reserves the definition itself depends upon the current technological state within a specific country and upon the economics of world trade in that particular material. It is therefore often a gross estimate based on a number of assumptions, especially about the consistency of the ore bearing body. Reserves, or economic resources, are defined within the Institute of Geological Sciences as those mineral resources which are workable under present socio-economic conditions. With

the development of offshore mining with its attendant law of the sea problems, and possibly the exploitation of Antarctica, difficulties of estimating resources are likely to increase.

While the raw materials specified (chromium, cobalt, hafnium, niobium, tantalum, manganese, molybdenum, titanium, tungsten, vanadium, yttrium) have formed the basis of the study, it has been possible to identify others which are considered strategic within the industry. Even iron, one of the most commonly occurring of all elements, could be considered strategic in that production tends to be concentrated in a few areas and there is a tendency towards dependence on one or two countries for supplies. However since there has never been any question of its being in short supply, iron has not been included. Nickel, also abundant, is even more concentrated in its source of supply and difficulties could be foreseen. Among the other metals identified as important or potentially important are: beryllium, germanium, lithium and zirconium.

While some of the metals, for example tungsten, are vital by themselves most are important in the formation of alloys. The major alloys in the aerospace industry are those based on aluminium, nickel, steel and titanium. In engine production nickel, steel and titanium are used respectively for the hot end, centre and the cold end. When combined with these basic metals, often in small quantities, the other strategics confer a variety of properties on the alloy. The major necessities are resistance to high temperature, corrosion and wear. These strategics thus provide hardness, strength, stiffness, oxidation resistance and a number of more specialised properties such as stabilisation and grain size control. Within any one alloy there is therefore a very sophisticated and complex balance and this militates strongly against substitution over any but a medium time space. Normally for a key engine alloy, with all the re-testing required this might extend to five years. Certain of the strategics are also used externally as coatings or sprays or in a way to confer certain properties on the surface molecular layers. To try alternatives or reduce levels of a particular metal thus requires acceptance trials. The leaner compositions might operate as efficiently but this means long term evaluation. Furthermore since the length of service expected is a vital element there will be an even greater time lag in adoption. In the aerospace industry there is of course research and development to minimise need for particular metals without sacrificing quality. However designs are produced without the factors of mineral economics in mind. It is clearly vital to have flexibility of design consistent with technology. Since the market price is likely to fluctuate, it would be impossible to design for known economic circumstances. Such rapid price changes have been seen over the recent past in the cases of cobalt, with the Shaba province conflict, titanium with the Russian withdrawal from the market and tantalum.

The aerospace industry thus uses low volumes of high quality and high price alloys. The main consideration must always be the characteristics of the metals not their costs or availability. The thrust of development is to improve the maximum power:weight ratio and to extract the optimum performance at minimum weight. Furthermore the element of reliability is always pre-eminent and in the case of military aerospace equipment, this might be described as ultra-reliability. As the criticality of a particular alloy is related so closely to its usage, there must always be major problems when substitution is contemplated. The properties of a potential substitute may be compared with that of its rival and clearly the two can never be entirely congruent. Thus difficulties may arise not in long term performance or resistance in hot corrosive environments but in terms of simple engineering. Furthermore the increased concentration on another element may not only affect the design but may make a change in strategic vulnerability.

The question must be asked as to what is the true economic value. It may well be that the cost of certain raw materials is very small compared with what is at stake, particularly in military fields. With the development of technology, the requirements for the construction of a particular piece of equipment will diminish as the buy:fly ratio improves. Indeed with the use of powder alloys and pressure moulding the amount of waste has decreased significantly. However overall the need for strategics is likely to increase as a result of the broadening range of products and costs overall will show an increase through price increases.

Thus substitution in so sophisticated an areas as the aerospace industry is very complex. As higher thrust is achieved, the environments in which the equipment has to operate become increasingly hostile, the requirements become more specific and the possibility of using alternative materials diminishes. At present for type testing, engines require 150 hours' running time before being sealed and certified. Any changes require a further type test to prove the new alloy. At a minimum this would take several months, costing perhaps half a million pounds. Therefore before any change could be seen in the consumption pattern, between four and five years might be required. Complete changes could take up to ten years although obviously in times of war standards would be changed and these time spans would have to be greatly reduced.

Furthermore, apart from the scientific and technological problems, substitution may

be constrained by:

(a) difficulties such as inertia and investment provision within the industrial structure itself;

(b) social factors ranging from employment provision to pollution;

(c) psychological problems particularly those concerned with resistance to change.

Recycling also of course affects supply problems and can lead to diminished vulnerability. In the case of alloys containing only a very small percentage of the particular metal there are obvious problems but the recovery industry is itself developing a new range of techniques. Of particular interest is the recovery of germanium from flue dust and other minerals such as vanadium may be recovered from pulverised ash. Since the material requires little in the way of transport costs and is already in a form amenable to mineral extraction, far lower concentrations than those obtaining in ore can be considered potentially viable.

Commercial aspects

In examining potential blockages and even the amount of any mineral in transit between the mine and the aerospace industry, the various stages in the commercial pipeline need to be taken into account (Fig 5). In most cases there is an elemental supplier who imports the mineral and then despatches it to the alloy manufacturer. From there it goes for fabrication before finally appearing at a particular unit of the aerospace industry. Thus there may be four or five stages in the cycle since it would normally be considered prohibitively expensive for the manufacturer to deal directly with the raw material supplier. However to guard against potential problems certain companies in the aerospace industry have entered directly into long term contracts with the suppliers. This has been the case with particularly vulnerable metals such as cobalt and titanium. This development may become more common as with economic recovery in the West prices are bound to rise and there could be more industrial unrest. It must always be remembered in this context that the smallest gap between supply and demand can lead to a very large price rise.

The amount of a mineral in the pipeline, awaiting processing, etc. can be considered part of the stockpile. With the current recession and cash flow problems, most companies hold only minimal stocks but clearly a national stockpile under government co-ordination and control could alleviate at least short term stoppages in supply. Government subsidised private stockpiles might also provide an answer, but there would need to be clear guidlines about when the material could be used. Furthermore for any stockpile the form and quality of the raw material is crucial. With reduced refining capacity for certain metals it would be necessary to stockpile in beneficiated or even semi-manufactured form. Since it is the practice for aerospace procurement to plan for up to five years ahead, the stockpile requirements could be reasonably assessed. Information on European stockpiles is thin but it is known that France has fairly substantial provision which will be worth some £400 million by 1985 while the UK has spent £40-45 million to stockpile cobalt, chromium, manganese and vanadium. Besides Japan and South Korea, Spain, Sweden and Italy all operate stockpiles or are considering them. (8) With regard to stockpile maintenance there is the crucial problem of deterioration since many minerals need to be stockpiled in a highly specific form. The answer would be to store the material at one stage further back in the manufacturing process, but this presupposes that there is plant available to effect the final conversion. If such plant is not present and could not be economically established for the amount of material used, there must be a dependency upon a country possibly totally different from the original source. For example, Japan processes a range of materials such as silicon wafers and provides for them a major world repository. An important addition to any stockpile would be a data bank containing details of researched projects on such vital topics as substitution, conversion within the economy and recycling.

When supplies are limited and particularly where the usage is highly specific, investors may affect the commercial flow of the market. In general investment in strategic minerals is not a common way of building a portfolio but there are several brokers specialising in the field (9) As yet there has been little if any experience of selling under incipient conflict conditions to manufacturers. A strategics portfolio is of course a private stockpile and in the USA tax relief through the so-called 'Blue Sky' fund is planned. The recipient would agree to sell at a particular price, thus removing the major potential blockage in the system and indeed providing useful buffer stocks. However when problems of strategic mineral supply are considered the activities of investors must be taken into account, although experience shows that price manipulation may be successful in the very short term, but in the longer term it has always failed.

Quoted market prices refer to only very specific forms of each raw material and accordingly their use as a guide to changing strategic status has been criticised. Nonetheless there is generally a relationship between them and the materials in what

may be their more commonly used forms. Further, they are readily obtainable and they do encapsulate a range of factors, geological, political and economic. In this context therefore it is interesting to note the peak price period during 1978-80 which affected all the major strategics (Fig 6). This of course coincided with the effective start of the resource war scare. (10) The subsequent fall in prices has caused a temporary lull in anxiety but has obviously provided a good time for stockpile purchases. As Western economies recover investment interest can be expected in cobalt, chromium, molybdenum, niobium, tantalum and titanium. Additionally and possibly of more importance in the long term strategic argument, hafnium and yttrium will come under consideration.

Strategic considerations

The following key points therefore emerge for detailed attention and were investigated through interviews and literature surveys:

(a) the major uses for the aerospace industry of each raw material;

(b) possible substitution;

(c) the geographical sources of each raw material, the scale of production and the extent of reserves; (11-16)

(d) the trading patterns leading to an assessment of dependence by European NATO countries;

(e) the vulnerability of major supply sources.

## 2. RAW MATERIALS

Chromium

Chromium is a critical component of many alloy steels and is irreplaceable at anything approaching the same price. It is particularly vital in all heat-resistant stainless steels and no suitable substitute exists for it in high pressure, high temperature, corrosive environments. Furthermore in most of the alloys in which it is found, chromium is the major metal occupying between roughly 20% and 25%. For corrosion resistance a level of below 12% results in markedly decreasing effectivness. With developing technology its use in the chromising alumina treatment of the surface layers of alloys, giving them a higher oxidisation resistance, is becoming increasingly important. In the aerospace industry therefore chromium is one of the major metals used, particularly for the production of steel-and-nickel based alloys. For its other uses in less exacting environments, substitutes may be found although frequently at higher cost and lower performance.

Sources

While there would seem to be potential elsewhere, notably in Brazil, Sudan and China, chromium in workable quantities has a comparatively limited distribution. Only eight countries each produce more than 2%. Output is dominated by South Africa (32%) which has shown a notable increase in proportion over the recent past and the USSR (27%). Other important producers are Zimbabwe (6%), Turkey (6%) and the Philippines (4%) all of which have shown a general decline, and Albania (13%) which has shown an increasing production. Within Europe only Albania, Turkey and Finland are of significance. Despite the range of smaller sources, the dependence upon only one major producer outside the CPEs represents long term vulnerability.

This dependence is seen to be even more acute when world reserves are considered. They are virtually completely concentrated in southern Africa with South Africa (68%) and Zimbabwe (30%). In fact the figure for South Africa is somewhat arbitrary since reserves to a depth of 300 m are estimated at over 3,000,000,000 tonnes, a figure higher than that quoted on most lists of world reserves. Furthermore South Africa has consolidated its pre-eminent position through the development of first class technology. The argon-oxygen-decarbonisation process has been developed so that low grade ores can be used to produce stainless steel at very competitive prices. Thus while Zimbabwe has higher grade ore, the thin seams and comparatively inefficient production methods render it increasingly less competitive.

Chromium increasingly enters world trade as ferro-chrome, which itself varies in degree of beneficiation. However taking it as basically one commodity, it can be seen that South Africa again plays a dominant role. In 1980 some 800,000 tonnes of ferro-chrome were produced amounting to 60% of the ferro-chrome entering world trade and 30% of total world production. South Africa in fact stockpiles in the form of ferro-chromium since this is more immediately usable and a number of varieties can be retained. The recovery rate is about 9%.

At present the market for chromium is depressed and the supply of ferro-chrome currently exceeds demand. However as research and development programmes bear fruit and particularly governments implement stockpile programmes, the outlook could change.

Indeed the United States Bureau of Mines expects demand to increase from the 1978 base at an annual rate of about 3.2% up to 1990.

European NATO Trade

Imports of chrome ore and concentrates into NATO Europe are dominated by South Africa which accounts for about 50% and is by far the major supplier to all the main importers. Other important sources are Turkey, Albania and Madagascar, while Finland and Greece provide supplies on a much smaller scale, and the USSR has varied considerably in importance over the recent past. The Netherlands and Germany are re-export sources. For ferro-chrome, Zimbabwe, South Africa and Sweden are all important, other sources being Turkey, Albania and Finland with Germany the major re-export supplier. The movement of unwrought and wrought chromium is very small and sources are mainly within NATO Europe, although some supplies are received from the USA and Japan.

Thus the vulnerability of European NATO is all too evident with only one NATO country, Turkey, of any importance as a source of chromium. There is a very heavy dependence on southern Africa, particularly South Africa itself while Albania as a CPE and Finland and even Sweden as neutral countries could pose problems of reliability.

Strategic considerations

Chromium illustrates a clear case of strategic vulnerability with very heavy reliance upon one source outside the CPEs. Furthermore with suppliers and particularly South Africa becoming more involved in beneficiation, low priced ferro-chrome can be produced, underpricing the industries of the consumer countries. As a result, plants for example in the USA and Japan have been closed. Thus there is increasing reliance upon South Africa which is supplying at present some 45% (by metal content) of requirements and selling not only the raw material but also power and technological expertise. Moreover this is compounded by the fact that the consumers seem reluctant to diversify sources even within the limited range available. This undoubtedly results from the reliability and quality of South African supplies. Also in the obvious country for development, Zimbabwe, the future appears rather uncertain.

Cobalt

Cobalt has a wide ranging significance as it is increasingly used with nickel and chromium alloys for parts of the air frame manufacture while being of specific importance in engine construction. It is also vital for the machine tools used to produce the various parts and also in a number of other aspects such as thrust rings for propellers and engine bearings. It is thus a high consumption metal the chief uses for which can be summarised as follows:

(a) a solid solution strengthening agent in nickel based alloys and some steels;

(b) a base for, in particular, wear-resistant alloys.

For its strengthening properties there are alternatives such as nickel, although others are much scarcer than cobalt itself. For wear-resistance there are no satisfactory substitutes. It would therefore be possible to build aero engines without cobalt but they would be more expensive in a number of ways. Following the world cobalt shortage in 1978 the use of cobalt was reviewed in the aerospace industry and while the range of uses has increased there is a trend towards a reduction of the metal in alloys. Possible substitutes include alloys containing nickel, vanadium, chromium and tungsten.

Sources

Cobalt is mostly recovered as a by-product of copper and nickel mining but world production is highly localised. Total annual production is approximately 30 x $10^3$ tonnes, but there has been a decline recently. Only eight countries each produce more than 1% of the total, and production is dominated by Zaire (40%) and Zambia (9%). Zaire's predominance has tended to decline recently but it is still obviously the key source. The only European production is in Finland (4%). Of the CPEs, Cuba and the USSR produce about 6% each.

With regard to reserves, nine countries have over 1% of the total but again Zaire (38.5%) and Zambia (12%) are dominant. There are no reserves of this order in Europe, Finland having only 0.6%. There has been something of a glut on the market recently and producer stocks may be as high as 20,000 tonnes. Furthermore recycling techniques have been improved and it is possible that 12% of the market is in fact secondary cobalt. Zaire has therefore been cutting production but Zambia, with a view to the future, has commissioned a new plant at Kitwe which when its second phase is complete, will virtually double Zambia's production capacity.

Seabed nodules contain an estimated 225 million tonnes of cobalt or over seventy times the current world reserve. However the necessary large scale investment for production from these seems at least ten and more probably twenty years away.

Over the next year or two there would seem to be no difficulty with supplies of cobalt but with the increasing interest in stockpiles and the long overdue re-equipment of civil airlines, the picture could change rapidly.

European NATO Trade

Bearing in mind the political problems in southern Africa and also the fact that a high proportion of Zairian cobalt passes through Belgium, it is hardly surprising that reliable data are hard to collect. Indeed there is a certain reticence in publishing cobalt returns in national statistics. This doubtless results partly from lack of information but also from a desire for confidentiality and as a consequence, aspects of the movement of cobalt in world trade cannot be stated with certainty. The main, indeed the only stated source of ore and concentrates listed for Europe is Morocco. Cobalt is traded most commonly in unwrought, ferro and waste forms while there is some movement of wrought metal. The major sources are Zaire, Zambia, Norway and to a much smaller extent, Finland. Secondary sources are Sweden, the USA and the United Kingdom. This pattern emphasises again the very strong dependence upon very few primary sources, with Zaire, which supplies approximately 65% (by metal content) completely predominant.

Strategic Considerations

Cobalt is medium scale in production and at present the consumption is well below production. However, it can be confidently predicted that the two will match again in the near future at which time the activities of investors may prove important. However the major source of vulnerability is the dependence upon one key less developed country with something of a history of instability. Cobalt accounts for 15% of the value of exports from Zaire but only 2% of those from Zambia, but such figures offer both producers some scope for manipulation. The coincidence of very limited sources in a geopolitically unstable area means that the problems of cobalt supply are potentially acute.

Hafnium

While hafnium is not used in the manufacture of air frames, it is quite important in the production of special alloys for jet engines since it control grain size in casting alloys and can confer ductility. It therefore governs the structure of parts which are under severe stress. However it is in the densifying of castings that hafnium is probably unique. As a result, for example, it promotes high creep strength and therefore lengthens the life of blades. The amount used is very small but there are no long term alternatives.

Sources

Hafnium production comes almost entirely from the mineral zirconium which usually contains about 1% of hafnium. It is recovered as a by-product in the production of hafnium-free nuclear grade zirconium-based alloys. It is therefore available at reasonable cost while the demand for reactor grade zirconium lasts. Statistics for world primary hafnium production are not available but the main source is concentrates from beach sands in the USA, Australia and India. South Africa also has extensive but lower grade beach deposits. There is no adequate source of zirconium in Europe. The scale of production is very small and the number of companies involved very limited. Therefore statistics tend to be confidential. Hafnium is produced as sponge and crystal bar, the USA producing 45 tonnes annually of the latter.

World reserves, judging by the distribution of zirconium, exceed 500,000 tonnes. Thus it can be concluded that potential hafnium supplies far exceed current demand.

Since there are no substitutes for hafnium in its major applications, prospects for hafnium look sound so long as the zirconium market remains healthy. At present recycling is insignificant.

European NATO Trade

Owing to its mode of production hafnium is only quoted in the trade statistics in its unwrought form. Furthermore few countries include it within their statistics. Imports into Europe are virtually all recorded as from the USA although it is known that some supplies come from Australia.

Strategic considerations

Since hafnium is unique and also produced on a very small scale there is some obvious vulnerability. Despite the variety of sources, dependence upon the USA could also present problems, not only with regard to maintaining the 'Atlantic Bridge' but also if American demand should rise. Furthermore it seems likely that investors will increasingly take an interest in hafnium.

Manganese

Manganese is an essential ingredient for all alloy steels 91% of it being used in the metallurgical industry. Its properties are to strengthen the steel in its own right and to desulphurise it. Nickel would provide some substitute but is expensive, while effective desulphurising agents are available but are themselves scarce.

Sources

Production at about 28 x $10^6$ tonnes is very much greater than that of all the other strategics considered. It is dominated by the USSR (39%) and South Africa (22%) but six other countries each produce more than 1% of the world total. Included among them are: Brazil (8.5%), Australia (7.5%), Gabon (7%), India (7%) and China (6%). Altogether some 45% of production is within CEPs. Thus although there is rather wider choice of source, the pattern is not unlike that of chromium, with heavy dependence upon South Africa. There is no manganese production in Europe.

With regard to land based reserves the position of South Africa (53%) is even more dominant. The USSR possesses about 26%, Australia 9%, Gabon 5.5%, Brazil 3% and India 1.5%. Thus if CPEs are excluded South Africa possesses almost 75% of the world reserves. However reserves of seabed nodules are estimated at 2 x $10^{10}$ tonnes, and when these become available the picture will alter very considerably.

Since conditions are so closely related to those of the iron and steel industry, the market has been depressed recently. The production of ferro-manganese has also been at a level well below capacity and this has posed a number of problems. Basically ferro-manganese production is still considered of sufficient strategic importance for major investment even though the market is presently adverse. Therefore the question arises as to whether to maintain a strategic industry in an increasingly uncompetitive environment. As the steel industry recovers, so the tendency for all producing countries to beneficiate is almost certain also to increase. This will clearly affect alloy producing companies in the consumer countries and lead to even greater dependence upon the producers. In this of course the trend is for manganese to parallel chromium. As the capacity to smelt ferro-manganese declines so countries become more vulnerable to supply interruptions and less capable of processing ores held in a stockpile. Figures for recovery rates are not available.

European NATO Trade

Of all the strategic minerals under consideration the trade figures for manganese are much the most difficult to interpret. Manganese as ore, by far the most significant quantity, and in its ferro form is listed under a range of different grades. For ore and concentrates South Africa is by far the most important source for all the countries of NATO Europe apart from France, supplying 50% of imports. Next in order of significance are: Gabon (20%), Brazil (11%) and Australia while supplies are also obtained from Congo, Ghana and Morocco. The main sources for re-export are Belgium and Germany. Ash and waste are re-exported within Europe, but primary producers significant in the ferro-manganese trade, are South Africa, the USSR and Brazil. However re-export within Europe is more important and the leading countries are: Norway, Spain and Sweden. Manganese unwrought and wrought occupies a comparatively modest position in the trade statistics, the leading primary producer being by far South Africa. Thus South Africa dominates the manganese trade, supplying over 40% (by metal content). However the contribution of easily the leading secondary supplier, Norway, must be added since South Africa is its primary source, and the figure then exceeds 52%. Gabon provides approximately 15% (by metal content).

Strategic considerations

The scale of production is large and at present there is a surplus of manganese. While there is a limited range of sources, it is the reliability and quality of product which inclines the European countries towards South Africa. Gabon is a less developed country but manganese accounts for some 18% of the value of its exports. In the slightly longer term the lack of beneficiation facilities could pose further problems, but then other sources, such as Brazil, may supply relief.

Molybdenum

Approximately 80% of molybdenum is used in the iron and steel industry and the production of super alloys. In the manufacture of air frames molybdenum is critical for all low alloy steels and cannot be replaced. For engines it is used as an inter-metallic compound and also with tungsten for spray coatings. Molybdenum is further required for bearings and thrust rings. Within the aerospace industry molybdenum is a comparatively high usage metal, the amount being possibly half that of cobalt. The main properties are implanting strength, hardness and corrosion resistance to steel. It is also important in nickel-based alloys.

Sources

Molybdenum is a relatively common element, recovered from the working of many porphyry copper deposits. As copper capacity is now far beyond requirements, molybdenum should not be in short supply. However only five countries each produce more than 1% of the world total which is about 100,000 tonnes. The USA (60%) is completely dominant, the other major producers being Chile (14%), Canada (11%), USSR (9%) and China (2%). While the number of sources is therefore limited the fact that almost 75% of the production occurs within developed countries, lessens vulnerability.

World reserves are rather more widely spread although the USA (54%) and Chile (25%) still predominate. Other countries with significant reserves are: USSR (7%), Canada (6.5%). Peru (2.5%), China (2.5%), Iran (1.5%) and Mexico (1.5%). With regard to vulnerability the pattern of reserves parallels that of production.

There was a sharp increase in demand and production in the late 1970s but by 1980 a decline had set in. In fact the surge of 1979 is still being felt with new capacity being opened as late as 1981. While the main implications for molybdenum are closely tied to the steel industry and must wait for its recovery, conditions are favourable for the development of a new range of high technology uses. In particular research into high temperature steel has shown the benefits of including molybdenum. Therefore it is possible to forecast a modest increase in the market over the near future.

European NATO Trade

For ores and concentrates, much the most important trading form, the chief suppliers are the USA and Canada followed by Chile. While there is some re-export from the Netherlands, Germany and the United Kingdom. Ash and waste presents a most complex picture since there is re-export between the NATO countries but there are also imports from Austria, the USA and Niger. The ferro-molybdenum trade is dominated by Austria and Sweden although the main NATO countries apart from the United Kingdom are all involved. Again with unwrought and wrought molybdenum several countries are concerned but Austria and the USA are dominant. The molybdenum trade is very much dominated by the USA which provides about 65% (by metal content), Canada (18%) and Chile (12%), although the importance of non-NATO European countries particularly Austria and to a lesser extent, Sweden, must be born in mind. Problems of supply would therefore be concerned mainly with the 'Atlantic Bridge'.

Strategic considerations

The scale of production is within the medium range and at present there is no shortfall. There is a range of sources but the consumers tend to rely very heavily upon the USA. However should supplies be endangered Canada and Chile would seem to provide reasonable alternatives. From the trade lists it would appear that most of the European NATO countries retain sufficient beneficiation capacity.

Niobium (Columbium)

Niobium is important in the production of a range of steels, alloy steels and super alloys. In the aerospace industry it is used to stabilise stainless steel for air frames and also for welding. It is also used extensively in engine production for minor alloying, stabilising stainless steel, precipitation hardening, in nickel-based alloys and in wear coatings. There is also some interchange with titanium for corrosion inhibition in steel. The amount used is small but the properties are vital particularly in nickel-based, steel and titanium alloys.

Sources

Workable niobium sources are very highly concentrated and excluding the CPEs for which no figures are avaialble, there are only three countries each producing more than 1% of the world total. These are completely dominated by Brazil (87%) although Canada (11.5%) is also important. There are very small sources of niobium in Portugal and Spain. Reserves display a similar distribution with Brazil (70%) by far the most important, followed by the USSR (15%) and Canada (2.5%). The statistics thus reveal an extremely high degree of dependence on basically one source.

Despite the general economic decline, the demand for niobium remains relatively strong although increased stocks have accumulated. In fact during 1981 world niobium capacity increased through developments in both Brazil and Canada. Recovery is insignificant at about 2%.

European NATA Trade

For ore and concentrates niobium and tantalum are generally grouped together and this therefore rather obscures the pattern. The major suppliers of niobium are Canada and Brazil. The USA is predominant in other forms but the amounts are insignificant. The statistics reveal that Canada still dominates the trade supplying over 30% (by metal content) but more detailed investigation shows, at least for parts of the aerospace industry, total dependence upon Brazil.

Strategic considerations

While the scale of production is medium and at present probably exceeds demand, there is some room for investors in the market. The major strategic problem occurs when the range of sources is considered. Canada has only limited reserves and if not at present, at least in the future, there will be very heavy reliance upon one mine in Brazil.

Tantalum

In the aerospace industry tantalum is not used in air frames but in engines it is employed as an alloy strengthening element either by itself or with niobium. For this the amount is very small, a maximum of about 10%. Its major importance is as a strengthener in nickel-based alloys but it has been used as pure tantalum in for example the production of the RB211 heat shield. However even where it is important the use of higher performance powders has allowed economies to be made.

Sources

Total world production is about 440 tonnes and has shown a decline since 1979. There are five significant producers with Brazil (24.5%) and Canada (24%) the major sources. Others are Thailand (15.5%), Australia (12%), Nigeria (7%) and Mozambique (6%). If production from tin slags is added the world total is virtually doubled, with the greatest production being in Thailand, Malaysia, the USSR and to a lesser degree, Zaire. Thus although production is very small and this in itself could lead to problems should demand rise, the sources are widely spread. Furthermore there are very limited supplies within Europe, in Portugal and Spain.

Eight countries each have more than 1% of world reserves although dominant by far is Zaire (48%). Australia has 17.5%. Nigeria 9.5%, Thailand 6%, the USSR 6%, Malaysia 4.5%, Brazil 4% and Canada 1%. Although the Third World predominates, reserves are reasonably spread within the developed world and the CPEs.

Owing to substitution the more economical use of the metal and the general economic recession, demand for tantalum has fallen considerably. This contrasts sharply with the supply gap evident in the recent past and alleviated largely by the development of Australian sources. Recovery rates average about 8%.

European NATO Trade

For ore and concentrates the main sources are Canada and Brazil, followed by Malaysia (largely from tin slags) and Nigeria. Tantalum in other forms is important mainly from the USA although one or two European countries do use Australia as a source. While there is a strong dependence upon Canada the range of options is comparatively large and does not appear to pose strategic problems.

Strategic considerations

The potential difficulty lies in the scale of production which is small. At present there is insufficient demand even for this amount, but should the situation change, prices could rise sharply and supply difficulties could result. The present range of sources within the developed and less developed world militates against problems of concentration.

Titanium

The bulk of titanium ore, both ilmenite and rutile, is used for the production of titanium dioxide, the major pigment in nearly all white paint. This accounts for approximately 92% of the ore. Of the remainder the bulk is used for metal production and of this 60% is used for the aircraft and aerospace industries and a further 20% for steel and other alloys.

Within the aerospace industry titanium is one of the major metals used and is considered vital. It has a very high specific strength and specific stiffness and the modulus is between that of steel and aluminium alloys. It is used for precipitation hardening in nickel-based alloys and for corrosive inhibition in stainless steel. Because of its high strength it is a major component at the cold end of engines, for example for fan discs. Typically the alloy used for fan blades contains 90% titanium, 6% aluminium and 4% vanadium. The major ore is rutile, ilmenite being more for the commercial side of the market.

Titanium is also being used for highly stressed components in missiles, rockets and space capsules, as well as armour plating for airborne military equipment. Increasingly titanium carbide is becoming important in the machine tool industry in providing both coatings and complete tool tips. With such versatility, substitution for titanium is likely to lead to a loss of efficiency. For example carbon fibre composites may replace it, but they are very expensive. Furthermore a new aluminium alloy containing lithium, copper and magnesium is under test. For corrosion resistance there can be an interchange with niobium. However the range of applications

for titanium is increasing all the time and it seems highly unlikely that it will ever be less vital for the aerospace industry.

Sources

Titanium is widely distributed and in fact of the structural metals only aluminium, iron and manganese are more abundant. The major problem is the process of extraction, smelting and fabrication, all of which are expensive. Since titanium is obtained from ilmenite, rutile and slags and production is measured in sponge and pigments, the interpretation of statistics is more complex than for the other strategics. World production of ilmenite is about 5,000,000 tonnes the dominant producer being Australia (28%). The other leading producers are: Norway (15.5%), Canada (15%), USA (12%), USSR (9%), South Africa (7%), Malaysia (4%), India (3.5%) and Finland(3%). Both Canada and South Africa produce from slags. The world production of rutile is about 400,000 tonnes of which Australia produces about 70%. The other main producers are: South Africa (11%), Sierra Leone (8%) and Sri Lanka (4%). Thus with rutile there is a very heavy dependence upon Australia, and Europe has no production. Canada is the dominant producer of slags followed by South Africa. The production of titanium metal is almost equally divided between the developed countries and the CPEs, with a world total of just under 110,000 tonnes of sponge. Only five producers are listed: the USSR (43%), USA (28.5%), Japan (26%), United Kingdom (2.5%) and China.

World resources of ilmenite are fairly widely spread but only eight countries each possess more than 1% of the world total. These are: India (23%), Canada (22.5%), Norway (18.5%), South Africa (15.5%), Australia (8%), USA (7.5%), USSR (2%) and Finland (1.5%). Rutile reserves are also widely distributed, although Brazil is dominant with 78.5%. Other leading countries are: Australia (8%), South Africa (4%), Italy (3.5%), Sierra Leone (2.5%), USSR (2%) and USA (1.5%). For rutile then while there are supplies in Europe there is a heavy dependence upon one country, Brazil.

Both the production and consumption of titanium sponge have continued to show increases but the markets for both ilmenite and rutile have continued to remain depressed, despite the fact that in 1981 the USSR became an instant buyer. The increasing range of applications would seem to ensure the health of the metal market, and indeed titanium is one of the few strategics in the production of which aerospace companies have invested directly.

European NATO Trade

Tables for ore and concentrates contain ilmenite and titanium, the major sources being: Australia, Norway, Canada and South Africa with more minor quantities from India, Sierra Leone and Sri Lanka. In other forms of the raw material, the trade is very small. Ash and waste is imported from the USA, Canada and South Africa, while for the ferro-alloy, Norway is the leading source. Titanium unwrought and wrought comes principally from the USA and Japan although the USSR is also a supplier. The range of sources is therefore comparatively wide with Australia supplying about 36% (by metal content), Norway 34% and Canada 27%. There could be difficulties with the maintenance of the 'Atlantic Bridge', the length of sealanes and the limited dependence upon the USSR. However NATO Europe is clearly well placed with regard to beneficiation.

Strategic considerations

Although rutile is produced on a fairly modest scale it is difficult to contemplate problems of ore supply. Much more of a limitation is the production of sponge which is more sparsely distributed both in amount and geographically. All three key suppliers, Japan, the USA and the USSR could reduce exports as a result of rising home demand. Furthermore Japan presents problems of distance and clearly under certain conditions supplies from the USSR would not be expected.

Tungsten

Tungsten has a range of unique properties and is also largely resistant to corrosion, imparting great hardness, strength and resistance to wear. Its main uses are in the production of tungsten carbides and alloy steels. Tungsten carbides are vital in the production of equipment requiring extreme wear resistance but substitutes, in all cases inferior, are generally available for uses other than rock drilling. Similarly for alloy steel there may be other possible replacements but none entirely satisfactory and no acceptable substitutes are currently available for the electrical uses.

The aerospace industry is a medium user of tungsten. In air frame construction there are no alternatives and for engines, tungsten is vital, by itself, with carbides for tooling etc. and in wear applications. It is also used for wear, erosion and oxidisation resistance when plasma-or-flame sprayed. Tungsten is further used in bearings and thrust rings. Overall its major use is in strengthening cast nickel-based alloys and with the drift from wrought to cast alloys its importance will increase.

Sources

World production is about 51,500 tonnes and is very widely spread. The leading producers are China (29%) and the USSR (18%). Other producers of note are: Australia (6.5%), Bolivia (6.5%), Canada (6%), USA (5.5%), South Korea (5.5%), North Korea, (4%), Thailand (3.5%), Portugal (3%), Austral (3%) and Turkey (2%). Within W. Europe, France, Portugal, Spain and Austria all produce moderate amounts of tungsten. With such a wide spread of sources and, particularly with tungsten in Europe, there does not seem to be a major problem of vulnerability.

World reserves are also widely spread although again China is dominant with 52.5%. Other countries with major reserves are: Canada (10.5%), USSR (8%), USA (4%), North Korea (4%), Turkey (3%) and South Korea (3%). The pattern of reserves is therefore similar to that of production except that China is relatively under-producing while the USSR is over-producing.

Tungsten has retained its demand despite the world-wide recession although there have been some cutbacks. With a variety of new tungsten projects planned there would seem to be a more than adequate supply of the metal for the future. Furthermore recent emphasis on foreign trade by China will greatly influence the amount available. Recycling is also important with a recovery rate of about 23%.

European NATO Trade

The major source of ore and concentrates is China, followed by Portugal, Bolivia and Australia. There is little trade in other forms of tungsten, the main sources being Austria and South Korea, with Sweden and the USA involved to a lesser extent. Thus there is no distinct pattern of dependence although there is clear dominance by China (about 10% by metal content) which is likely in future to increase. However a wide range of European countries maintains the capacity to produce ferro-tungsten even though China is again important.

Strategic considerations

Although the tonnage required is comparatively small, there must be disquiet about the increasing dependence upon China. Given the pattern of world reserves, there would seem, at least in the medium term, to be little alternative.

Vanadium

Vanadium is chiefly important as an alloying agent in armoured steel and in the production of titanium alloys. In the aerospace industry it is important as a toughener in cobalt-vanadium tool steels and for this there are no alternatives. It is also vital in providing strength at high temperature in steel and nickel-based alloys. Its importance in the 6:4 titanium alloys (aluminium 6%: vanadium 4%) has already been mentioned. The aerospace industry is thus a small user but vanadium is vital.

Sources

World production is about 35,000 tonnes and is dominated by South Africa (33%) and to a lesser extent, the USSR (29%) and the USA (13%). Other producers are China (11%) and Finland (8%). Thus there is production in Europe but for the developed countries there is dependence upon South Africa. The pattern with regards to reserve reinforces the position of the two leading producers, South Africa having 49.5% and the USSR 46%. In fact the only other country with more than 1% is Australia. However since vanadium is generally recovered as a by-product or co-product reserves are not fully indicative of available supplies. At present prices though, South Africa is clearly the dominant source. Recovery rates are about 8%.

With an increased availability particularly as a result of Chinese intervention in the market and the decline of world steel production, the market has been rather depressed. However world consumption still rose and there are plans for development not only in China but also in Venezuela and New Zealand. Therefore it can be concluded that while the range of applications will probably increase the actual supply will remain sufficient.

European NATO Trade

Vanadium ore is of no significance as a raw material and therefore trade in ore and concentrates is generally not listed except in the case of Belgium which receives supplies from Norway. With ash and residues the main source is given as secret but others listed include Mozambique, China and South Africa. The sources of ferro-vanadium are principally Austria and Noway while vanadium, unwrought and wrought, is imported on a comparatively small scale from Japan, South Africa and the USA. However vanadium imports in chemical form are particularly important and are dominated by Finland and South Africa, followed by Austria. Despite European supplies therefore there is a clear dependence upon South Africa, which supplies approximately 27% (by metal content).

Strategic considerations

Despite being a commonly occurring mineral the installed capacity for extraction is important and this leads to a marked dependence upon South Africa. With the South African domination of world reserves, this position is likely to be reinforced in the future.

Yttrium

The use of yttrium in the aerospace industry is extremely small and there seems to be little concern about supplies. It is used with magnesium and is a constituent in some blade alloys. It is a constituent of both nickel-based and cobalt-based super alloys giving resistance to erosion and also as a coating for turbo blades in engines. The other potential use within industry is in the production of lasers in which in the form of yttrium-aluminium garnet, it can give very fast pulses of the order of a few pico-seconds.

Sources

Statistics for yttrium production are incomplete since those for the USA are withheld for reasons of confidentiality and those for Canada are not available. However the total is probably between 515 and 600 tonnes. The major producer is Australia (approximately 30%) while India and Malaysia are also important.

With regard to reserves India is dominant with over 52%. Australia (15.5%), USA (9%), Brazil (6.5%) and Canada (6%) are also significant.

As improved technology and research lead to increasing demands there seems little doubt that these can be met. It is probable that the world's undiscovered resources are large relative to any expected demand. At present recycling does not occur.

European NATO Trade

Yttrium appears separately in the trade statistics which show that Austria, Belgium and Germany are sources for other parts of Europe. Presumably the yttrium originates mostly in Australia with possibly some import from Canada and the USA.

Strategic considerations

These must revolve mainly around the small scale of production since the range of sources is comparatively wide. Clearly, should demand rise and prices increase, investors could well affect the market.

## 3. THE COUNTRIES OF EUROPEAN NATO

While elements of the aerospace industry are represented in all the countries of European NATO except Iceland, the industries of West Germany, Italy and the UK are quite clearly the most important. Since it has been associated in many European projects and since it is all so closely integrated into NATO although not a member, France must also be included.

For all the raw materials described, the countries of European NATO, with only minor exceptions, are 90% import dependent, the figure varying from approximately 91% (cobalt and tantalum) to 100% (titanium). The only raw material for which this does not obtain is tungsten, for which the dependence is 58% (UK 56%). In the case of five materials, the dependence of France is rather lower than that of the other countries. None of the major aerospace countries has deposits of strategic minerals on any scale. In fact the only significant production is chromium (Turkey), clearly the most important, ilmenite (Norway) and tungsten (Turkey and Portugal).

An examination of the trading patterns reveals that three European neutral countries, Sweden, Finland and Austria, exercise a significant influence. Firstly in a period of increasing tension between West and East, their attitudes towards trading strategic minerals with NATO must be considered. Furthermore although it is one stage removed, there is still the basic dependence upon the original source of the mineral together with the vulnerability resulting from reliance upon processing abroad. All three countries trade in a restricted range of strategic minerals but all are important in the area of ferro materials.

Among the developed countries the major sources of strategic minerals for European NATO are: USA, Canada and Australia. All three suffer to a certain extent from the problem of distance, the first two with difficulties of maintaining the 'Atlantic Bridge' and Australia with very long sealanes to be protected. Apart from this the main difficulty with the maintenance of supplies from the USA could well be that the particular minerals are required for internal consumption. Developing countries, at different states of development, but important for the supply of strategics present rather different problems. Since many are highly dependent upon the export of raw materials for their economic wellbeing and since in any case this may be controlled

by multinational corporations, there appears to be little coincidence between political and economic instability. In general, supplies do not appear to be disrupted by political change, a point shown vividly recently by continuing supplies of chromium from Zimbabwe. However in each there are possibilities of supply disruption through civil unrest, sabotage, local conflict, government expropriation and possibly the activities of Soviet surrogates.

In many ways for European NATO the most important country, neither developed nor developing, is South Africa. Apart from the various threats to its stability, particularly in the medium to long term, South Africa also poses a basic moral dilemma. For chromium and manganese and to a lesser extent vanadium and titanium, South Africa is a major producer and also possesses great potential for further development. Despite the current depressed state of the market there is great underlying strength resulting from:

(a) the enormous scale of reserves;

(b) the highly developed infrastructure;

(c) the abundant powers of beneficiation;

(d) the political and commercial stability; and above all

(e) the technological expertise.

Furthermore through its infrastructure South Africa controls most of the mineral exports from the developing countries of southern Africa

## 4. STRATEGIC CONCLUSIONS

The term 'strategic' when applied to a raw material implies a range of factors, geological, economic and political. Some of these can be quantified others are largely conjectural. Therefore to attempt a weighting is a particularly complex problem, and forcasts far into the future extremely hazardous.

(1) Raw materials

(1) Most at risk through the potential instability of sources are cobalt, chromium and manganese. In the longer term, offshore mining could alleviate the problem for cobalt and manganese.

(2) Most at risk through the concentration of sources are the above with the addition of, particularly, niobium. There could also be short term problems with nickel.

(3) Most at risk through reliance upon a CPE producer is tungsten.

(4) Most at risk through the small scale of production is hafnium.

(5) Most at risk through the reduction or lack or installed extraction or beneficiation plant are vanadium and titanium. Increasingly chromium and manganese in particular could also be affected.

(6) Most at risk overall are chromium, niobium and cobalt

(2) European NATO countries (Fig 7)

(1) All are, with very minor exceptions, highly import dependent, with France rather less so than the others.

(2) There is a high degree of dependence upon southern Africa and in particular South Africa.

(3) There is a marked secondary dependence particularly on neutral European countries.

(4) There is a tendency to rely on a restricted range of sources. The neutral countries and Japan show that this may be rather less necessary than is commonly supposed.

(5) There is little dependence on Warsaw Pact sources.

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Fig. 1 THE PROBLEM

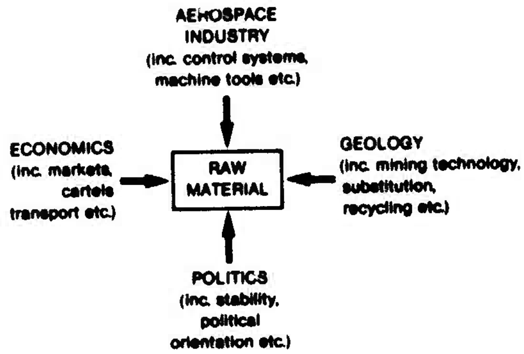


Fig. 2 CRITICALITY

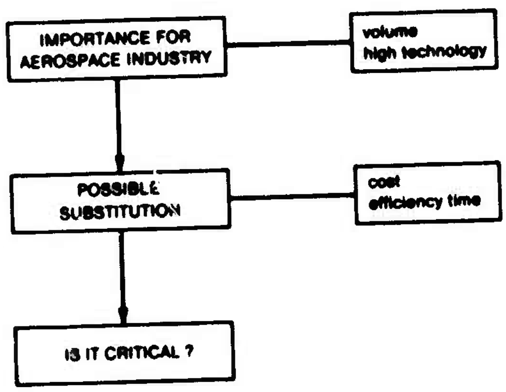


Fig. 3 SUPPLY CONCENTRATION

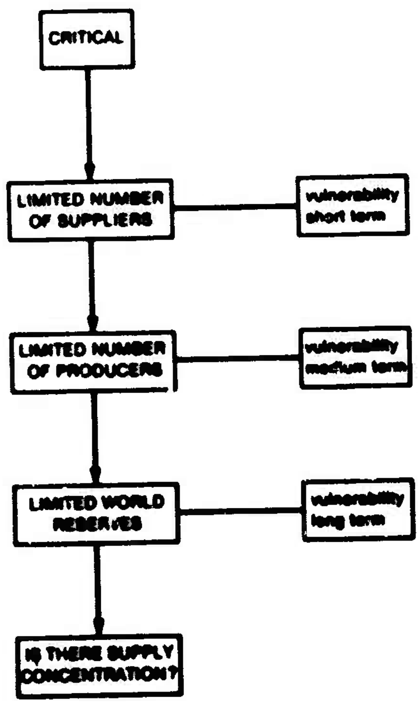

Fig. 4 POLITICAL VULNERABILITY

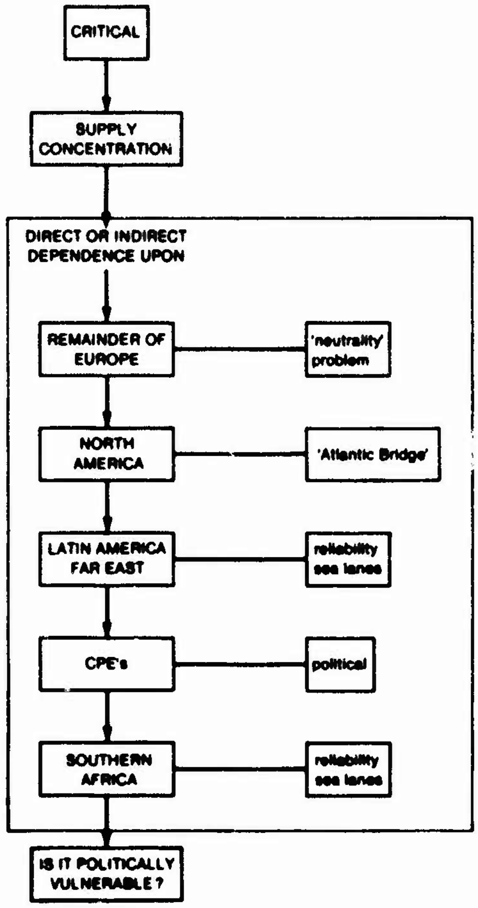


Fig. 5 STRATEGIC ALGORITHM

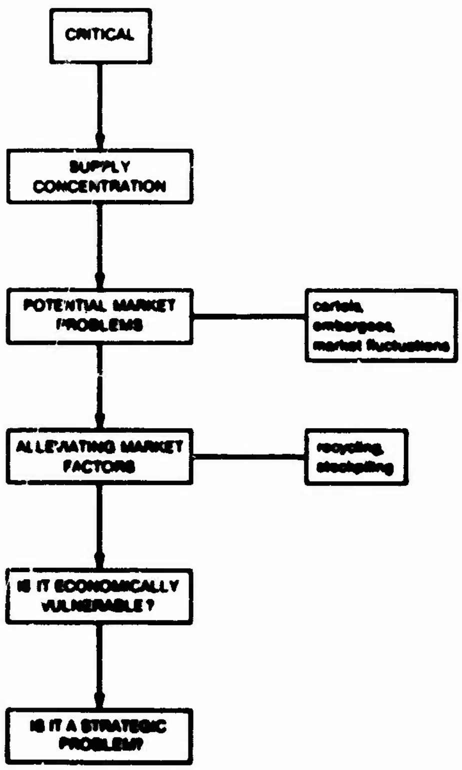

Fig. 6 PRICE FLUCTUATION

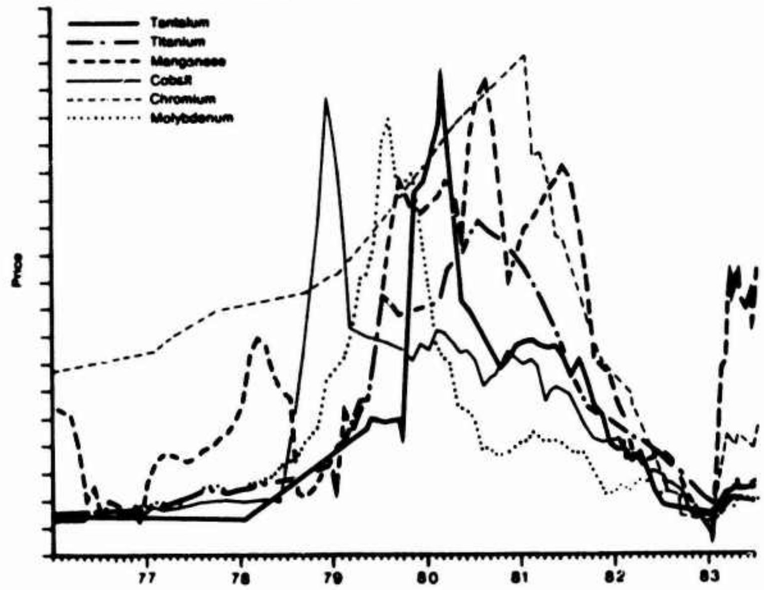

Fig. 7 EUROPEAN NATO: STRATEGIC MATERIALS DEPENDENCE